

# SPI DATA ANALYSIS: THE CESR/TOULOUSE APPROACH

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## ABSTRACT

In order to allow for an efficient and flexible scientific analysis of data from the SPI imaging spectrometer aboard INTEGRAL, I developed a set of analysis executables that are publicly available through the internet. The software is fully compatible with the ISDC data format. It complements software that is actually available through ISDC, and will be included in the next ISDC software release. This paper describes the design of my software system and provides a brief introduction to the executables.

Key words: SPI data analysis; software.

## 1. INTRODUCTION

SPI data analysis is a complex task. The data volume is important, the outstanding spectral resolution requires an accurate gain calibration, the important instrumental background demands a very precise modelling of its time variations, and the generally weak signals require sophisticated analysis methods. To perform SPI data analysis at the Centre d'Étude Spatiale des Rayonnements (CESR) in Toulouse, I therefore developed an efficient data analysis system that builds on the software kernel provided by the INTEGRAL Science Data Centre (ISDC). My software is available at the site <http://www.cesr.fr/~jurgen/isdc/index.html> and will be distributed in future versions of the ISDC Offline Science Analysis (OSA) system. At CESR, the system has been installed on a UNIX machine under Solaris 9, yet ports to Linux systems have also been performed successfully (the installation procedure is identical to that of regular ISDC software).

The core of the system is a library of C++ classes and functions (`spi_toolslib`) that provides all necessary functionalities for data analysis. Around this library, a number of analysis executables has been written. All software is documented by User Manuals. In particular, the `spi_toolslib` library is described in great detail, allowing the data analyst to

easily build new analysis executables using the available functions.

The starting point of the analysis is the prepared data provided by ISDC. These data are organised by satellite orbital revolutions (one revolution lasting typically three days), and are split into so called science windows, which generally either comprise a spacecraft pointing or a spacecraft slew. In the current approach only the pointing data are exploited.

Data analysis consists of 5 steps: observation group building, gain calibration, data preparation, data combination, scientific analysis (imaging, model fitting, spectral analysis) In the following sections these 5 steps are described.

## 2. OBSERVATION GROUP BUILDING

The entity of data that is combined for analysis is called an *observation group*. An observation group is a FITS file that contains pointers to all data that are associated to the observation. For all executables it is sufficient to provide on input an observation group, the software then automatically extracts the relevant information. Note, however, that the observation group contains the access paths to the individual data files, hence moving the data may invalidate the information stored in the observation group. Thus it is recommended not to copy or move observation groups or associated data.

The first step of the analysis consists in building an observation group (cf. Fig. 1). For practical purposes, I generally build an observation group per revolution. This leads to manageable data sizes and reasonable execution times for data preparation. In addition, this allows for a time-dependent gain calibration that may compensate detector drifts.

To gather the available science windows of an observation group, I use a UNIX script called `swg_build_list` that collects the *Data Object Locations* (DOLs) of all *science window groups* into a single ASCII file. A science window group is a FITS file that contains pointers to the data that are

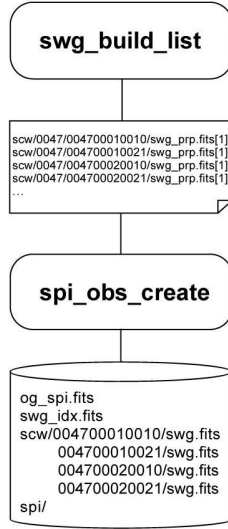


Figure 1. *Observation Group Building step.* A list of science windows, specified by the Data Object Locations (DOLs) of the science window groups listed in an ASCII file, are combined into an observation group. This is the starting point for SPI data analysis. The resulting data structure is depicted in the data container at the bottom of the figure.

contained within an individual science window. The ASCII file is then used as input for the executable `spi_obs_create` which builds the observation group. One may edit the ASCII file to exclude individual science windows from the analysis. In the current system, a science window is the shortest junk of data that may be analysed. Analysis of shorter periods, e.g. as needed for gamma-ray burst studies, has not been implemented so far.

### 3. GAIN CALIBRATION

The next step consists in gain calibration to convert the registered Pulse-Height Analyser (PHA) values for each event into physical meaningful energies (cf. Fig. 2). For this purpose, the line centroid in PHA units are determined for a couple of well selected gamma-ray lines of known energies that arise in the instrumental background (see Lonjou et al., these proceedings). Spectra of PHA values are built for each revolution using the executable `spi_gain_hist`, and line fitting is performed using `spi_line_fit`. In the actual approach, Gaussian shaped lines on top of a linear background are employed for fitting (this basically ignores the effect of detector degradation which leads to an extension on the left wing of the lines).

From the fitted energies, calibration relations are derived using the isdcroot scripts `gainResults.C` and `gainCalib.C`. The calibration relations for each revolution are then combined in an index table (using the ISDC executable `txt2idx`) that is passed to the

event histogramming software, which then handles the time dependence of the gain calibration.

Note that gain calibration files and indices are provided by ISDC and may also be downloaded on my internet site, hence normally the gain calibration step is not required for your analysis.

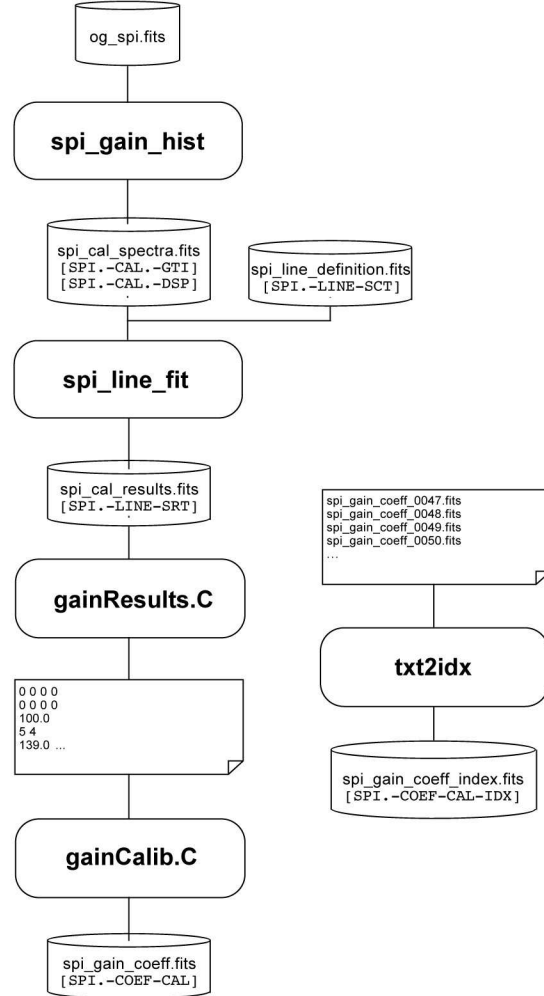


Figure 2. *Gain calibration step.* The input observation group contains a list of science windows, typically those of one satellite revolution. The resulting gain coefficient file contains calibration coefficients for this list of science windows. The coefficients for each revolution are combined into a calibration index allowing for time dependent gain correction.

### 4. DATA PREPARATION

The Data Preparation step consists in building the 3-dimensional SPI data-space for each observation group, which is spanned by spacecraft pointing, telescope detector, and photon energy (cf. Fig. 3). This data-space is stored in a FITS file with extension name `SPI.-OBS.-DSP`.

First, the energy binning of the data-space is defined

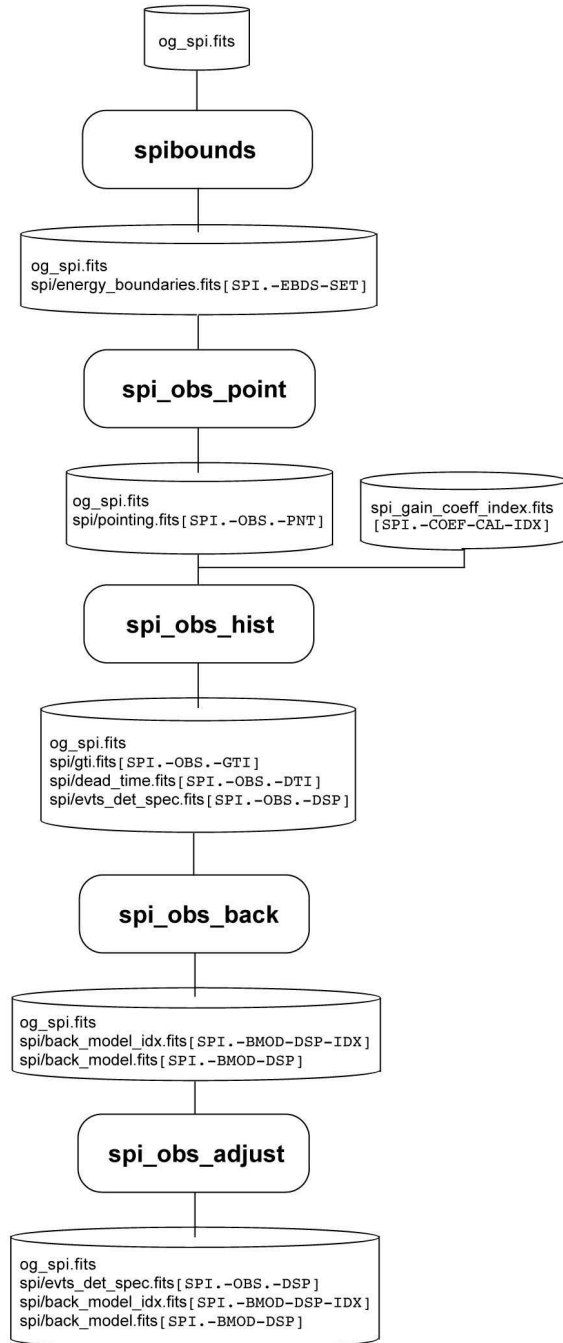


Figure 3. Data preparation step. The input observation group contains a list of science windows, the output observation group contains calibrated detector spectra for each pointing and pseudo-detector with the associated pointing, exposure, lifetime and background model information. Degradation effects have been corrected for. The output observation group is now ready for scientific analysis.

using the executable **spibounds** which adds a FITS file with extension name **SPI.-EBDS-SET** to the observation group that contains the lower and upper energy boundary for each of the energy bins.

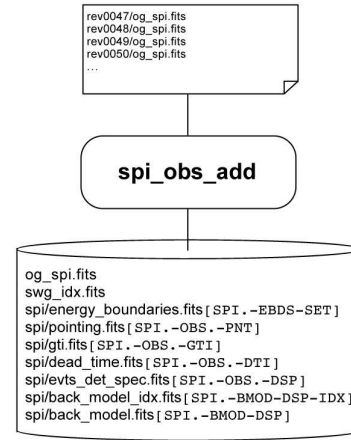


Figure 4. Data combination step. A list of prepared observation groups are combined into a single observation group. Background modelling and degradation adjustment may be applied to the combined data.

As next step, the available spacecraft pointings are extracted for an observation group using the executable **spi\_obs\_point**. This executable adds a FITS file with extension name **SPI.-OBS.-PNT** to the observation group that contains the start and stop time for each pointing, as well as the SPI telescope pointing direction (the misalignment between SPI and the spacecraft is taken into account at this step).

Now the observation group is ready for data-space building. This is done using the executable **spi\_obs\_hist** which adds three FITS files to the observation group: **SPI.-OBS.-GTI** which contains the Good Time Intervals for each pointing and detector as well as the effective exposure time, **SPI.-OBS.-DTI** which contains the Livetime for each pointing and detector, and **SPI.-OBS.-DSP** which contains the histogrammed photon data (in units of counts). **spi\_obs\_hist** automatically detects the data transmission modes of SPI (operational mode, spectral mode or emergency mode), and performs the required transformations to provide a homogeneous and clean set of prepared data.

Before the data can be analysed, a model of the instrumental background is required. Background modelling is performed using the executable **spi\_obs\_back** which adds a list of background model components to the observation group (extension name **SPI.-BMOD-DSP**). Note that the background model may consist of several components which are stored in separate data structures (yet in the same FITS file). These data structures are then combined by an index table that is attached to the observation group (extension name **SPI.-BMOD-DSP-IDX**).

Background modelling is of course the most delicate step in SPI data analysis, and for more information about the available background models the data analyst is referred to the **spi\_obs\_back** User Manual.

Finally, differences in the detector degradation between the histogrammed data and the background model components may be compensated using the executable `spi_obs_adjust`. This step is optional, but recommended for gamma-ray line analysis.

## 5. DATA COMBINATION

If the data preparation has been performed revolution-wise, the observation groups may now be combined using the executable `spi_obs_add` (cf. Fig. 4). Note that in principle several revolutions may be prepared in a single step, yet the execution time of the histogramming step (`spi_obs_hist`) rises non-linearly with data-space dimensions (due to the particular architecture of the FITS access routines).

`spi_obs_add` also allows to select a sub-range of energy bins from the input data, leading eventually to smaller and more manageable data-space dimensions. Background modelling (`spi_obs_back`) and degradation adjustment (`spi_obs_adjust`) may also be performed after data combination using the output observation group of `spi_obs_add` as input. This allows testing different background models and/or degradation corrections for the same data.

## 6. SCIENTIFIC ANALYSIS

Now, scientific analysis executables provided by ISDC, such as `spiros` for point-source localisation and spectral analysis, may be applied to the prepared data. In my system, two further executables are available (cf. Fig. 5). `spi_obs_fit` performs fitting of sky-intensity distributions to the data, allowing for morphology studies and spectral analysis. Various treatments of the instrumental background are provided, allowing for reduction of the systematic uncertainties in the data analysis.

`spi_obs_mrem` performs Expectation Maximisation image deconvolutions to extract sky-intensity distributions from the data. The implemented algorithm is also known as accelerated Richardson-Lucy algorithm, and has proven successful for the analysis of gamma-ray data for other missions. In the future, it is foreseen to implement also a Multiresolution analysis in this software, allowing to reduce statistical artefacts in the reconstructed intensity distributions for diffuse emission.

Both executables produce on output an observation group that contains the data that have been used for analysis. This means that if for example only a single energy bin has been selected for imaging analysis, the resulting observation group contains only the data and background model for this single energy bin. Or if the background model has been modified by `spi_obs_fit` during the fitting procedure, the resulting background model with the scaling factors applied will be stored in the output observation

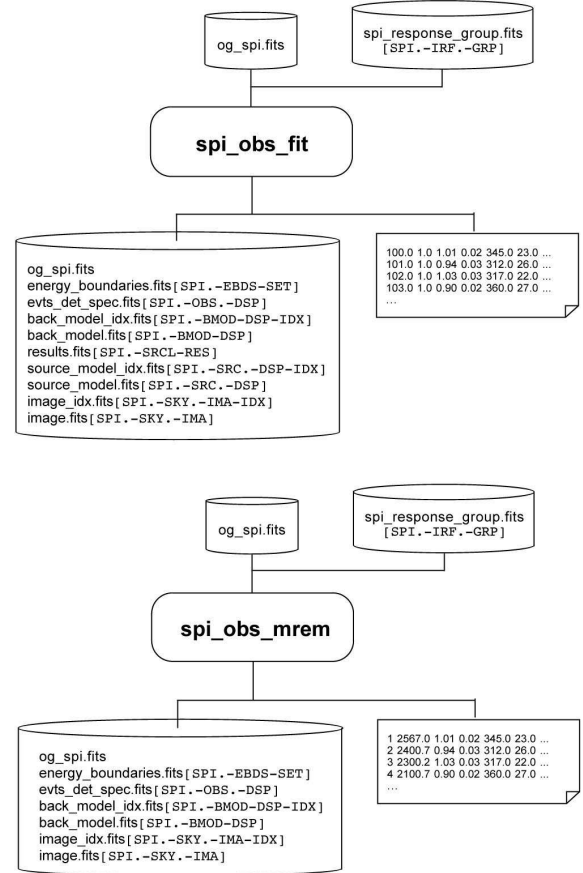


Figure 5. Scientific analysis step. The instrument response is used in this step. On output, an observation group is created that contains all data that have been used for the scientific analysis. An ASCII file contains the analysis results for quick display.

group. In a following step, this output observation group may then be used for example for imaging.

`spi_obs_fit` provides also an image on output which contains the best fitting combination of the model components that have been fitted to the data. In this way, a model intensity distribution can be derived from the data.

## 7. CONCLUSIONS

The software described in this article has been designed and coded to allow for an efficient and flexible scientific analysis of SPI data. I hope that the present article is particularly useful for INTEGRAL guest observers, and that the information provided will increase the reliability of the data analysis performed by non experts. Providing simple and robust software to the user community is certainly a prerequisite for the success of the INTEGRAL mission, hopefully allowing to achieve many new and interesting science results.